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DYNAMICS OF SUPERFLUID HELIUM IN LOW-GRAVITY

NASW-4803

FINAL REPORT

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1. INTRODUCTION

This report summarizes the work performed under a contract entitled "Dynamics of Superfluid Helium in Low Gravity". This project performed verification tests, over a wide range of accelerations of two Computational Fluid Dynamics (CFD) codes of which one incorporates the two-fluid model of superfluid helium (SFHe).

Helium was first liquefied in 1908 and not until the 1930s were the properties of helium below 2.2K observed sufficiently to realize that it did not obey the ordinary physical laws of physics as applied to ordinary liquids. The term superfluidity became associated with these unique observations (ref. 1).

The low temperature of SFHe and it's temperature uniformity have made it a significant cryogenic coolant for use in space applications in astronomical observations with infrared sensors and in low temperature physics. Superfluid helium has been used in instruments such as the Shuttle Infrared Astronomy Telescope (IRT), the Infrared Astronomy Satellite (IRAS), the Cosmic Background Observatory (COBE), and the Infrared Satellite Observatory (ISO). It is also used in the Space Infrared Telescope (SIRTF), Relativity Mission Satellite formally called Gravity Probe-B (GP-B), and the Test of the Equivalence Principle (STEP) presently under development. For GP-B and STEP, the use of SFHe is used to cool Superconducting Quantum Interference Detectors (SQUIDS) among other parts of the instruments. The Superfluid Helium On-Orbit Transfer (SHOOT) experiment flown in the Shuttle studied the behavior of SFHe. This experiment attempted to get low-gravity slosh data, however, the main emphasis was to study the low-gravity transfer of SFHe from tank to tank. These instruments carried tanks of SFHe of a few hundred liters to 2500 liters.

The capability of modeling the behavior of SFHe is important to spacecraft control engineers who must design systems that can overcome disturbances created by the movement of the fluid. In addition instruments such as GP-B and STEP are very sensitive to quasi-steady changes in the mass distribution of the liquid.

The CFD codes were used to model the fluid's dynamic motion. Tests in one-g were performed with the main emphasis on being able to compute the actual damping of the fluid. A series of flights on the NASA Lewis reduced gravity DC-9 aircraft were performed with the Jet Propulsion Laboratory (JPL) Low Temperature Flight Facility and a superfluid Test Cell. The data at approximately 0.04g, 1g ,and 2g were used to determine if correct fundamental frequencies can be predicted based on the acceleration field. Tests in zero gravity were performed to evaluate zero gravity motion.

2. FLUID MODELS

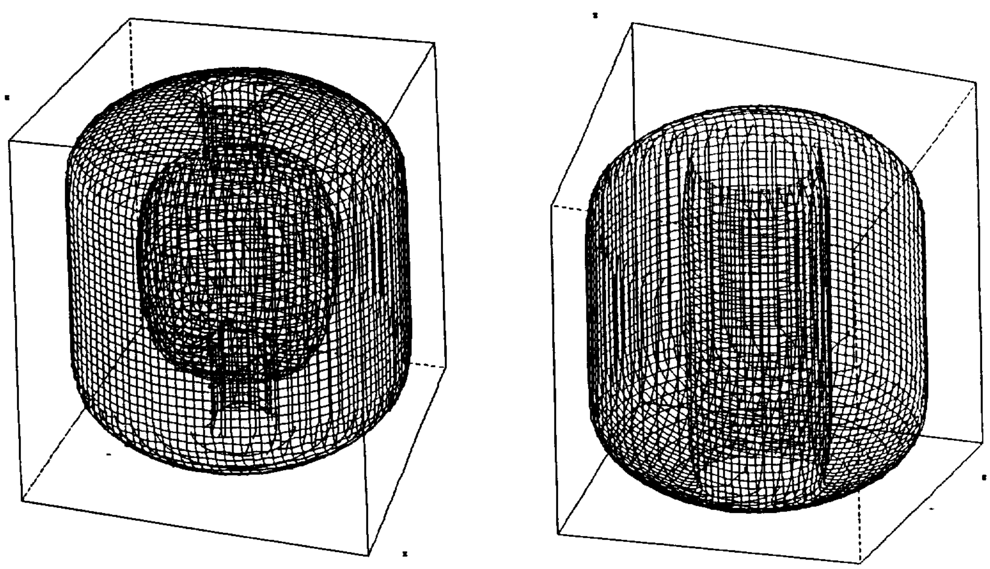
Two CFD codes were used in the study. The first is a commercial code called FLOW3D by FLOWSCIENCE in Los Alamos, New Mexico and is referred to as the single-fluid model in this paper. The second code is SFHe3D which was developed at Lockheed Martin by Dr. G. Ross, the Principal Investigator of this project at it's onset. The base code used for this latter model is FLOW3D.

2.1 SINGLE FLUID MODEL

FLOW3D is a general purpose program with many capabilities. The principal reason that it was selected for this project is it's well established capability of modeling three-dimensional fluid motion with a free surface.

The approach of FLOW3D is to subdivide the flow region into a grid of variable-sized rectangular cells. For each cell, values are retained for the basic flow quantities. Finite-difference approximations to the Navier-Stokes momentum equation are used. The code has many options for compressibility, various boundary conditions, and the use of moving, rotating, or accelerating reference frame. A full description of the code can be found in the FLOW3D User's manual (ref. 2).

This code was used extensively in the center-of-mass study of the SFHe in the GP-B dewar (ref. 3). The primary emphasis in that study was to determine the quasi-steady state distribution of the fluid in the rotating tank. The tank has a volume of 2500 liter with a center cylindrical section which contains the instrument package. Figure 1-1 shows the distribution of the fluid when the tank is approximately 85 percent full and rotating at 0.1 and 0.3 rpm. It can be seen that at the higher roll rate, the centrifugal forces become dominant over the surface tension forces. This leads to the liquid/vapor interface profile to become dominated by the centrifugal acceleration field.



W=0.1 rpm W=0.3 rpm

Figure 1-1: Single fluid model prediction of GP-B at different roll rates. Results show that at the higher roll rate, the centrifugal forces dominate.

This code was also used to determine the response of the fluid to disturbances and to gravity gradients as the vehicle orbits the Earth. This is of importance to the design of the spacecraft attitude control system which must have sufficient authority to compensate for disturbances due to fluid motion. Figure 1-2 shows the frequency of the fluid motion for different roll rates. Of importance to this project is that the code predicts frequencies proportional to the square root of the centrifugal force (i.e. linearly to the roll rate). Figure 1-3 shows the effect of some baffles on damping the longitudinal displacement of the fluid due to a disturbance in the longitudinal direction. It can be seen that adding more than three baffles does not add much further to the damping and a three baffle design was selected.

When predictions like these are being performed, it becomes very important to determine if these kinds of codes are adequately predicting the behavior of superfluid helium. Prior to using the codes, a number of verification tests were performed. These verification tests were done by comparing CFD results to data taken with Newtonian fluids. This project gathered data with SFHe.

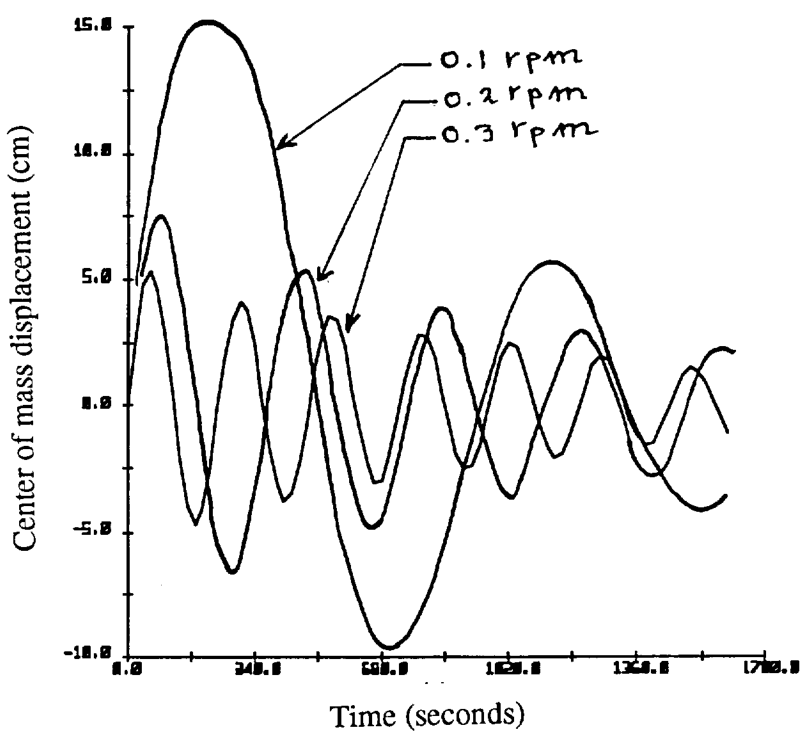


Figure 1-2: Single fluid model prediction of GP-B fluid motion frequencies. Results show that the frequency is proportional to the square root of the centrifugal force.

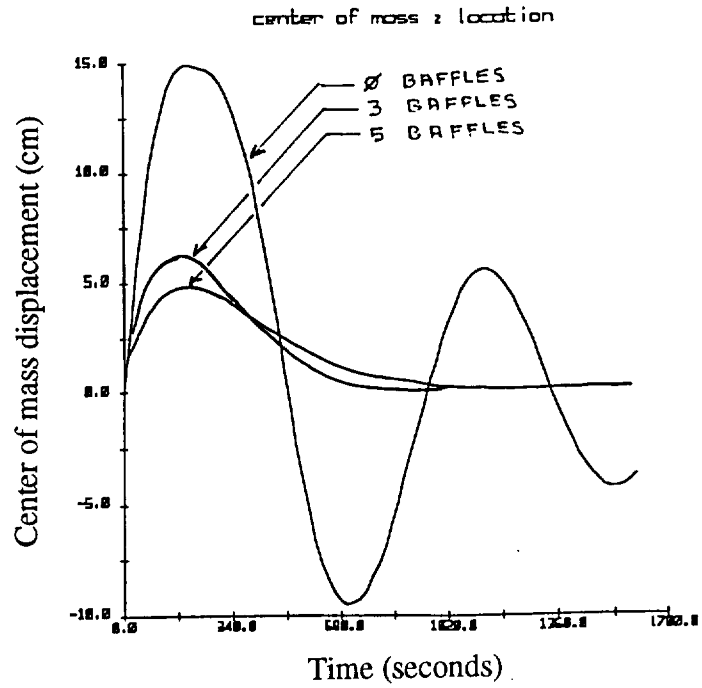


Figure 1-3: Single fluid model prediction of GP-B fluid damping. Results show that three baffles are sufficient to provide fluid damping.

2.2 TWO FLUID MODEL

FLOW3D was modified to incorporate the unique physics of SFHe. SFHe is considered to be a fluid that is made up of two components: a normal fluid component and a superfluid component. Above the lambda point all of the fluid is normal. As one lowers the temperature below the lambda point the percentage of superfluid increases and the amount of normal fluid decreases. The superfluid is considered to have zero viscosity and zero entropy. The thermal conductivity of superfluid is extremely large. Observations showed that superfluid helium can flow through very narrow passages with no friction unless the velocity does not exceed a “critical” value. It has become accepted that when the fluid is below this “critical velocity” there is no coupling between the normal and superfluid components. Above this “critical value”, the two fluids interact and there is a “mutual friction” that couples them.

This two fluid model of the fluid was the basis of SFHe3D. A detailed description of the code and implementation can be found in reference 4. The implementation required the addition to independently calculate the velocity fields of both the normal and superfluid components of HeII, calculate the differential velocity between the two fluids, the geometry-dependent critical velocity, and calculate the mutual friction between the two fluids when the differential velocity exceeds the critical velocity.

The results of simulations done with the two fluid model in comparison with the single fluid model show that the model results are not significantly different from each other in a 1-g acceleration field. This is since the 1-g field dominates over the mutual effect which are unique to the two-fluid model.

Of importance are results of simulations done with the two fluid model in zero-gravity. Results show that the nonlinear dependence of the mutual friction could produce changes in the fluid coupling resulting in a divergence in fluid flow directions of the normal and superfluid components. This effect can produce sudden shifts in the center of mass of the fluid and be of concern to attitude control engineers.

3. TEST EQUIPMENT

The major parts of the test equipment consists of a dewar containing the SFHe Test Cell and the Jet Propulsion Low-Gravity Aircraft Facility (Ref. 5). The size of the Test Cell was determined by the following requirements:

1) Capable of interfacing with the JPL Facility.
2) Large enough to last the duration of the low-gravity flight.
3) Shaped to restrict the motion to two-dimensional

Since superfluid helium is a cryogenic fluid, it must be contained in a reservoir that is isolated from the air to prevent condensation and freezing of air on the reservoir. This is the reason that such cold fluids are stored in "thermos bottles" called dewars. The dewar provides an evacuated space between the fluid's reservoir and the atmosphere. The evacuated space also provides a thermal barrier between the fluid and the ambient surrounding temperature. The evacuated space also prevents conduction of heat to the reservoir, however there is still a radiative heat load. Since the heat of vaporization of helium is so low, a shield at liquid nitrogen temperature is required to achieve any significant hold time of small quantities of helium. This type of dewar is referred to as a liquid nitrogen guarded helium dewar. In order to perform tests during which one can observe and record the motion of the fluid, the dewar must have a sight window.

A schematic of the dewar is shown in Figure 3-1. The Test Cell is inserted into a small vacuum jacket which is then submersed in the liquid nitrogen bath, as shown in the lower portion of the figure. The outer vacuum jacket has windows on each side in line with the windows of the inner vacuum jacket and the Test Cell. A picture of the dewar is shown in Figure 3-2.

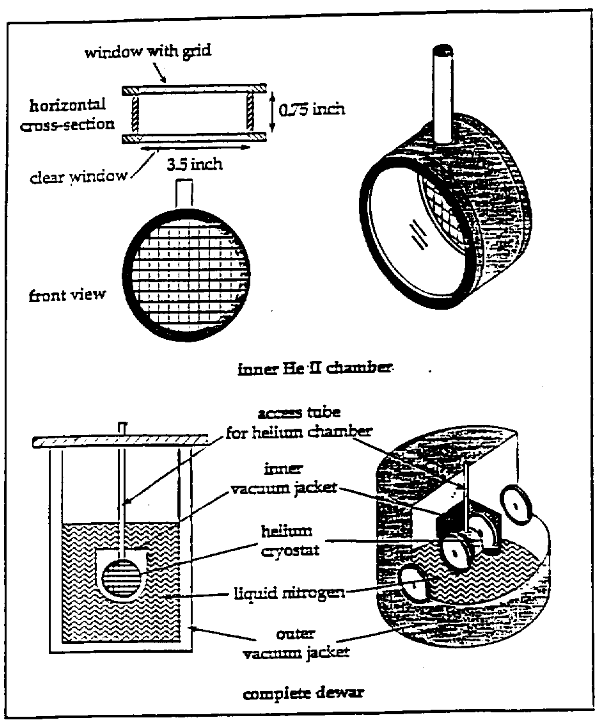


Figure 3-1: Dewar Schematic

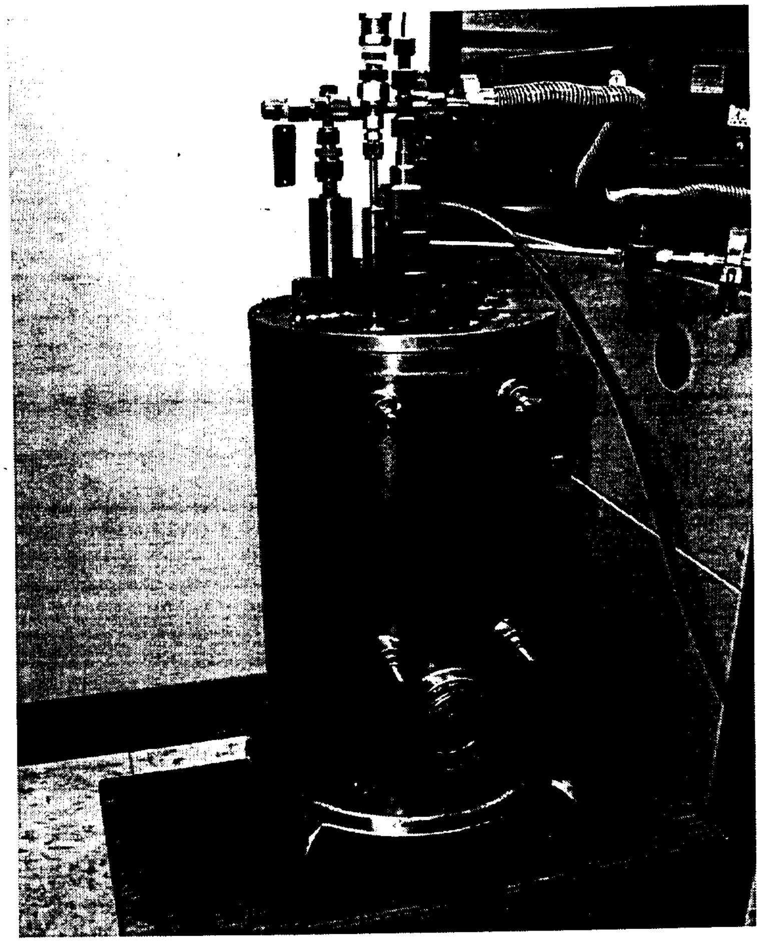


Figure 3-2: Dewar

A plumbing schematic is shown in Figure 3-3. The liquid nitrogen is vented to the atmosphere. The cold gas passes through a heat exchanger which warms it to ambient temperature and then through a relief valve. The superfluid helium tank is maintained at subatmospheric condition with a pump.

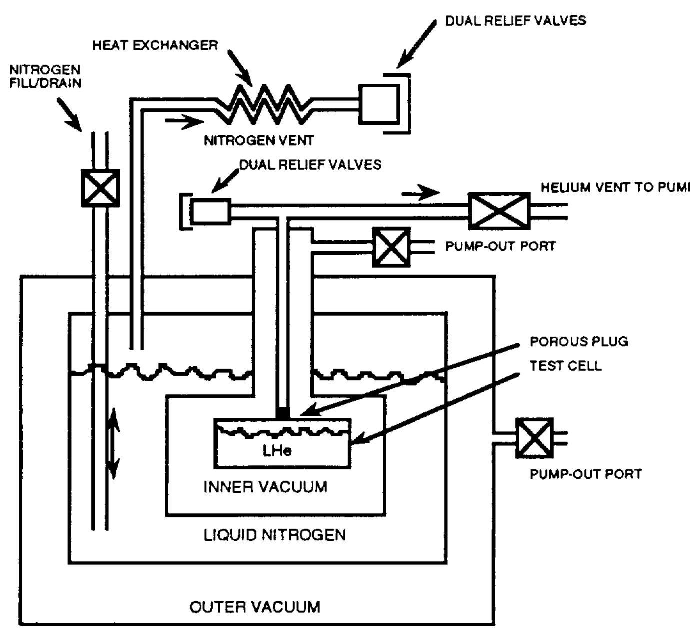


Figure 3-3: Plumbing Schematic

3.1 TEST CELL

The Test Cell is a 0.2 liter thin disk (8.89 cm dia., 3.18 cm thick) which restrains the fluid motion to 2 dimensions. Figure 3-4 shows a picture of the Test Cell.

The front and rear of the cell are made of Pyrex and the outer circumference is made of stainless. A single line is used for both the filling and venting. The front is used for viewing the fluid and the rear wall is used for backlighting. The rear wall is covered with a mylar sheet. The sheet is used to diffuse the light and provides a grid pattern that is used to measure the location of the liquid/vapor interface. The Pyrex pieces are sealed to the cell by use of indium.

The Test Cell is essentially suspended by the fill line. The length of the fill line is made as long as possible to minimize the thermal path from the ambient temperature zone. A set of glass fibers are used to stiffen up the line without providing a thermal short. Appendix A contains the mechanical drawing of the Test Cell.

In order to retain the fluid in the cell during low gravity operation and to only allow vapor to escape, a removable porous plug is used. A porous plug is essentially a porous media that utilizes the unique thermo-mechanical properties of SFHe for achieving phase separation. The porous plug assembly is removed during the filling process and then inserted once the Test Cell has been filled with normal boiling point liquid helium. The operations of the dewar are outlined in section 4.

Two germanium thermometers are placed inside to measure the temperature of the liquid. These sensors were calibrated prior to being installed. In addition the output of the sensors are compared to the visual indication of the fluid transition to superfluid helium condition which occurs at the lambda point. At the fluid transition to the superfluid helium state, the "boiling" of the fluid ceases. All the evaporation takes place at the liquid/vapor interface and the fluid becomes very calm.

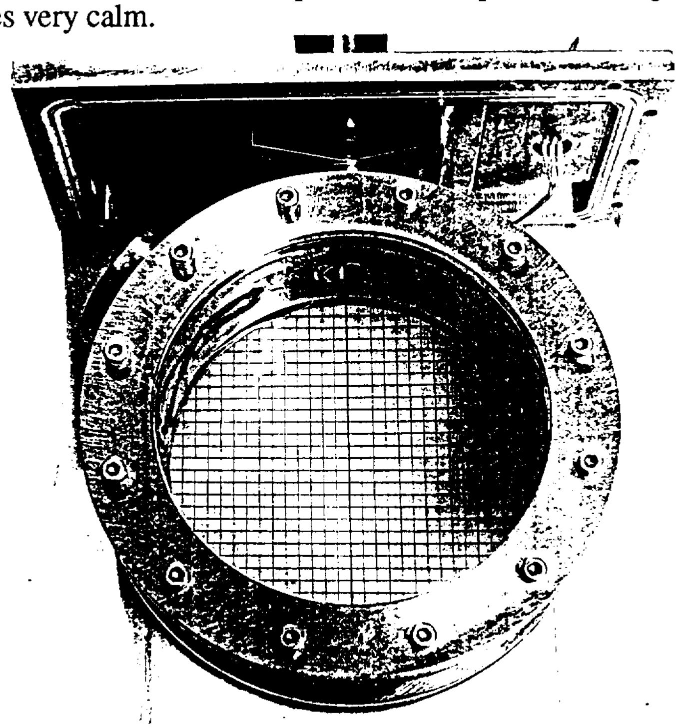


Figure 3-4: Test Cell

3.2 LOW GRAVITY TEST FACILITY

The JPL Facility consists of a Float Package and an electronic rack. The dewar is installed into the Float Package. The Float Package is designed to free-float in the aircraft cabin. The data acquisition system is mounted in an electronic rack that does not float.

The dewar is mounted to the float package frame at eight points. Each point has a rubber damper to reduce dynamic loads. The pump and plumbing networks are also mounted to the float package frame. The pump is used to keep the helium in a superfluid state. Affixed to the dewar is a video camera which views the helium through a mirror and the windows. Accelerometers are attached to the dewar. The accelerometers measure the gravity field in each of three axis. A schematic of the Dewar and Float package is shown in figure 3-5.

The electronic rack consisted of a power distribution system for the electronics and pump, a computer, a thermometer readout system, and a video system. The computer utilized LabVIEW to read time codes and acquire analog voltages. This produced time-tagged data and video. A description of the LabView data acquisition can be found in reference 6.

The float package frame and the electronic rack are only connected by electrical cables which transmits the video image and outputs of the accelerometers and thermometers.

There are a number of support equipment, such as the storage dewars for the liquid helium and the liquid nitrogen, leak detector, regulated gaseous helium, and transfer lines for the liquid nitrogen and liquid helium. These support equipment are required prior to the flight and are not carried on the aircraft.

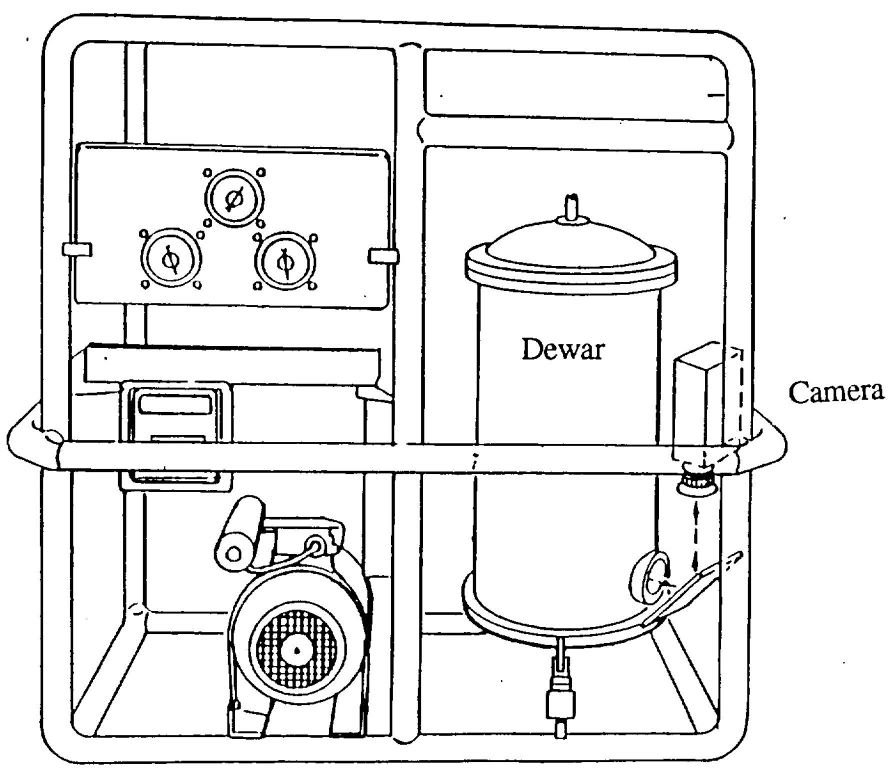


Figure 3-5: Schematic of Dewar and Float Package.

3.3 SAFETY DATA PACKAGE

An Experiment Safety Document was prepared and submitted to the NASA-Lewis Reduced Gravity Aircraft Program in accordance with requirements of NASA TM106755 entitled "Users Guide for NASA Lewis Research Center DC-9 Reduced-Gravity Aircraft Program". This document was prepared in collaboration with JPL. It contained all the test and equipment documents, analysis, and hazard analysis. This was the first cryogenic experiment flown by the NASA/Lewis Low Gravity Aircraft and therefore this package received good scrutiny by the NASA safety engineers.

The following is a list of the hazard analysis.

1. Cold Liquid/Gas impingement on personnel or equipment during flight.
2. Cold Liquid/Gas impingement on personnel or equipment during ground filling operations.
3. Inert gases being continuously vented into aircraft cabin resulting in a loss of oxygen content.
4. Inert gases being vented into aircraft cabin at high rate due to a loss of dewar vacuum resulting in a loss of oxygen content.
5. Overpressurization of cryogenic tanks resulting in an explosion.
6. Surfaces cooled to dangerous temperatures.
7. Breakage of outer Pyrex windows of dewar.

4. OPERATIONS

There are two important aspects that effected the operations of this experiment. First is that the helium must be conditioned to superfluid helium temperature and second is that the small test cell has a limited life before it has all evaporated.

As mentioned earlier, superfluid helium is the state that liquid helium has when cooled below the lambda point of 2.176K. Typically one fills a dewar with NBP helium at one atmosphere and then cool it down by evaporative cooling. This is done by actively pumping on the helium. In this process, the temperature of the helium decreases along it's vapor pressure curve. The cooling is done by evaporating the remaining liquid. In doing this process, one is left with only a 45-50 percent full tank. Once the temperature reaches 1.8K, the vapor pressure is only 12.4 torr and therefore if a tank is to be topped-off, one must perform a subatmospheric transfer. This procedure is not trivial and requires elaborate support equipment. For this project, it was determined that the extra expense of this operation was not justified and all tests were performed with a maximum of a half full tank.

The second aspect that effected the test is that the parasitic heat load would cause evaporation of the helium and therefore the duration that one has to get the data once the tank was filled is limited. Figure 4-1 shows a plot of the amount of helium remaining once the helium has been conditioned to superfluid helium. It can be seen that once the Test Cell is filled, the test must be carried out fairly quick.

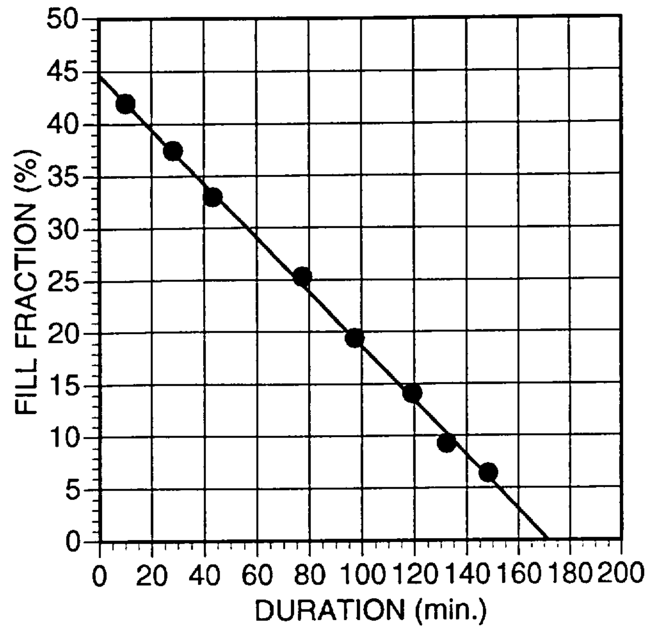


Figure 4-1: Typical Hold time of Test Cell

4.1 GROUND OPERATIONS

The preflight ground servicing of the dewar took place in two phases. The first was carried out a few hours prior to flight. This entitled cooling the dewar down and filling both the nitrogen reservoir and the liquid helium Test Cell. This was done to allow the dewar to reach thermal equilibrium. The second phase would take place right before the aircraft was ready to move out to the runway. This second servicing took only 15 minutes.

Due to the ceiling height required for the liquid helium transfer line, the servicing needed to be performed outside the cabin. Figure 4-2 shows the servicing being performed on a lift by the loading door of the aircraft. Once the Test Cell was filled, the Float Package was brought into the aircraft and secured as shown in Figure 4-3. During these servicing periods, a helium leak detector would be monitoring the vacuum space between the helium and the nitrogen.

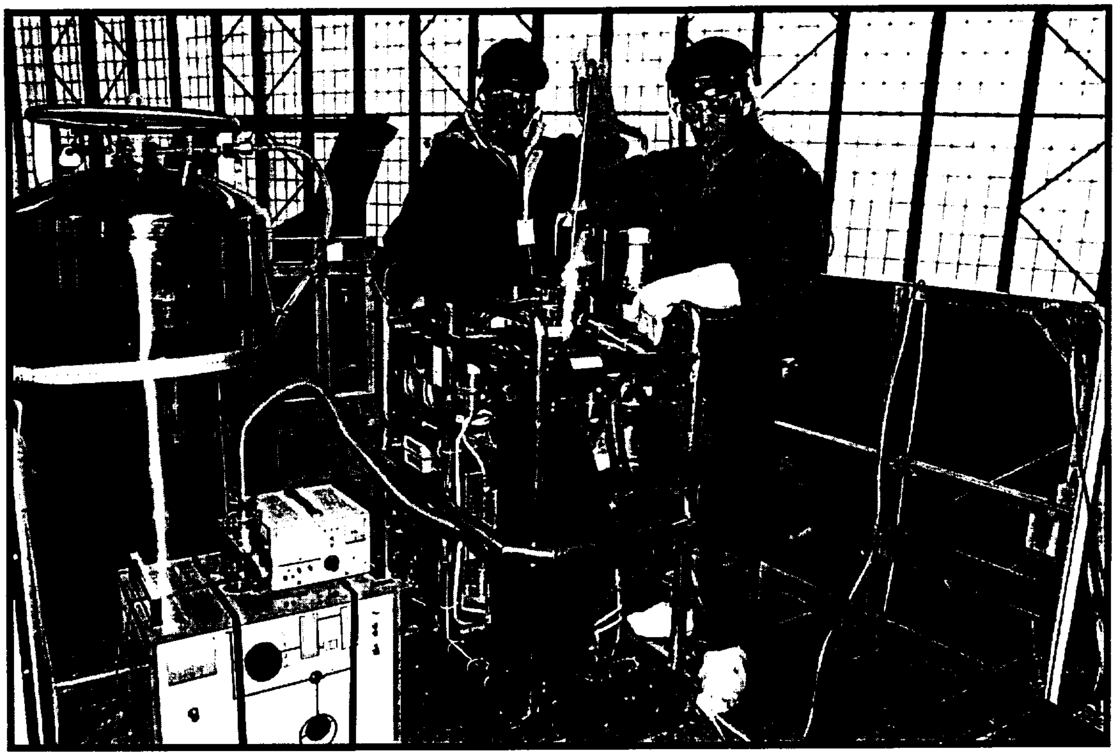


Figure 4-2: Servicing next to Aircraft

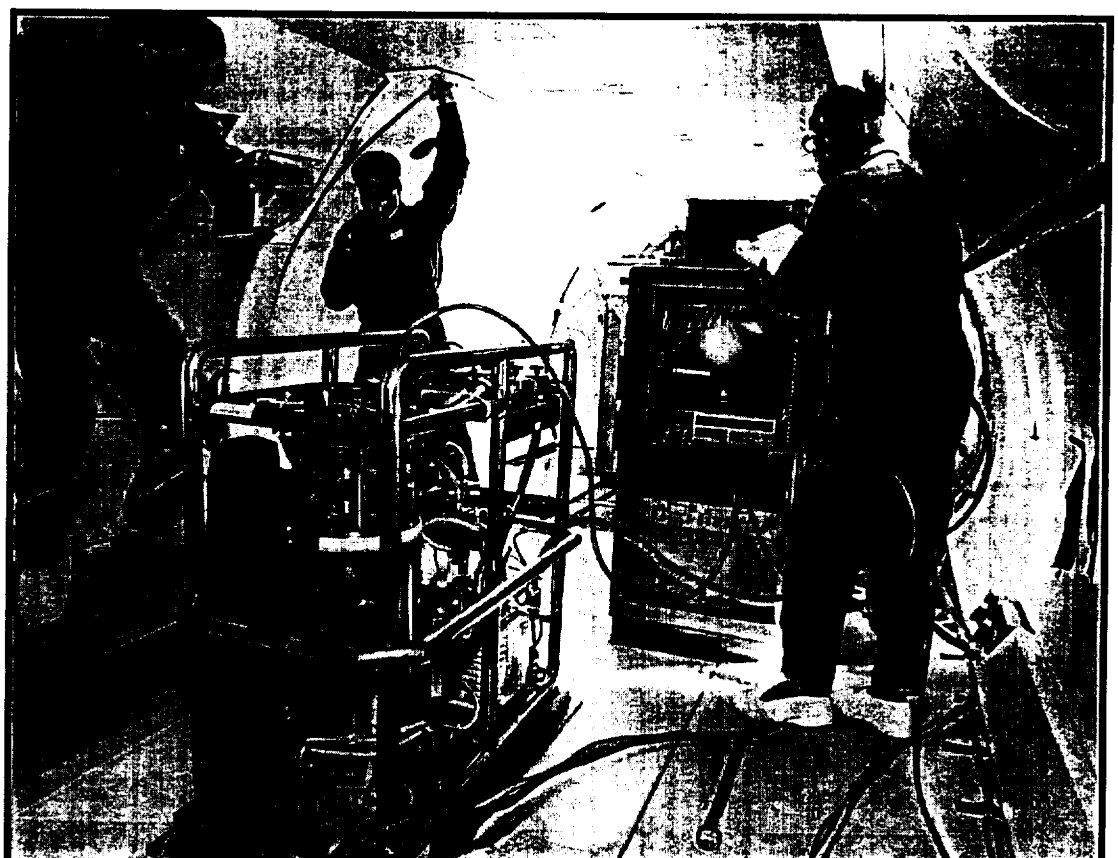


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Figure 4-3: Low-Gravity Facility inside Aircraft

4.2 INFLIGHT OPERATIONS

Typically, the time between once the aircraft is in the air to the test site was 20-30 minutes. This time was used to get the Test Cell and dewar ready for test. Once the aircraft was off the ground, the conditioning of the helium was performed. This usually required about 10 to 15 minutes. Once this was performed, the porous plug assembly was positioned in place to seal the vent line and only allow vapor to be removed from the Test Cell.

Since the viewing of the Test Cell is through the liquid nitrogen and there were no provisions to control it in low gravity, the liquid nitrogen had to be drained. If this is not done, the sloshing of the liquid nitrogen would obscure the viewing of the helium. The draining was performed by attaching the nitrogen fill/drain line to the aircraft overboard vent system. The rate of drain was manually controlled by use of a valve. The drain rate was regulated such not to get the aircraft vent line below it's minimum allowed temperature.

The test series would consist of 45 parabolics with short breaks to allow the aircraft to turn around once it would reach the end of the flying zone. During this time, the temperature of the bath would be changed if required. For tests at the intermediate level of gravity, the Float package would be kept secured to the floor and the trajectory of the aircraft adjusted to get accelerations at 0.04g. Figure 4-4 shows a typical acceleration profile during this test which shows a low gravity period of 15-20 seconds. Prior and after the low gravity period, the aircraft would experience levels on the order of 2-G which were sufficiently long to gather at that level.

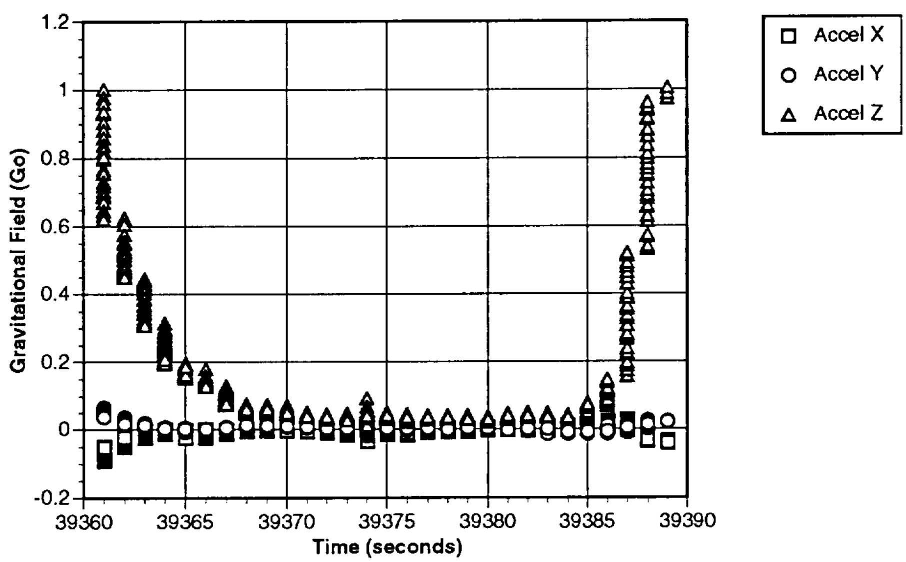

Figure 4-4: Typical DC-9 gravitational field profile. Periods of 15-20 seconds of low gravity were achieved during this 0.04g parabola.

For the tests were very low-G were required, the float package would be initially kept secured to the floor and once the aircraft entered the low gravity period, the float package would be lifted off the floor and released. If the package would not be released gently or if the aircraft attitude would change, the float package would drift and collide with the walls of the cabin. The duration available for test would therefore be much shorter. A very good test would get about 6-7 seconds at the very low-G. Figure 4-5 shows the package being released after being lifted from the floor. After entering the zero gravity trajectory, the fluid would transition from the high-g profile to the zero-gravity profile. The fluid was then disturbed and the resultant motion recorded.

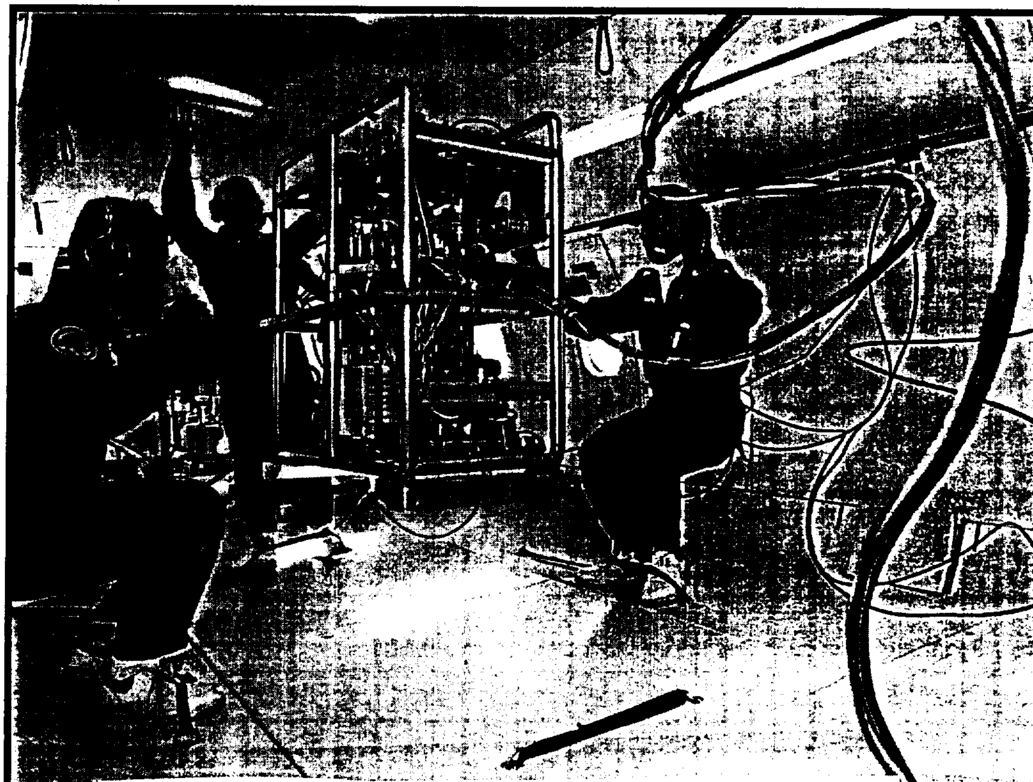

Figure 4-5: Free-floating of the experimental Float Package.

5. PREDICTION AND TEST RESULTS

5.1 ONE-G BEHAVIOR

A series of ground slosh experiments was performed as a verification of the codes in 1-g (ref. 7). The liquid in the Test Cell was disturbed to create a slosh wave oscillating in the plane of the cell. The slosh wave was measured. The results of multiple runs were manually phase-shifted into a single set. An exponential decay curve has been fitted to the data to estimate the damping coefficient for the helium at that combination of fluid temperature and tank fill ratio. Figure 5-1 shows some of the data taken at a temperature of 1.7K. The exponential damping coefficient δ from the equation $A_t = A_0 x\ 10^{-\delta t}$ was calculated for each data set and plotted against the fill fraction as well the relative proportion of superfluid and normal fluid as shown in figure 5-2. The test results show a weak correlation with temperature (i.e. proportion of superfluid to normal fluid) and a strong correlation with fill levels.

Both single-fluid and two-fluid models were run for the Test Cell geometry. Figure 5-3 shows the fluid slosh amplitude at a particular location in the cell for both simulations in the same manner that the data was reduced for the experimental runs. Both the single and two fluid models predicted essentially the same damping coefficients as the test. This suggests that the 1-g field is far more influential than the mutual friction effect.

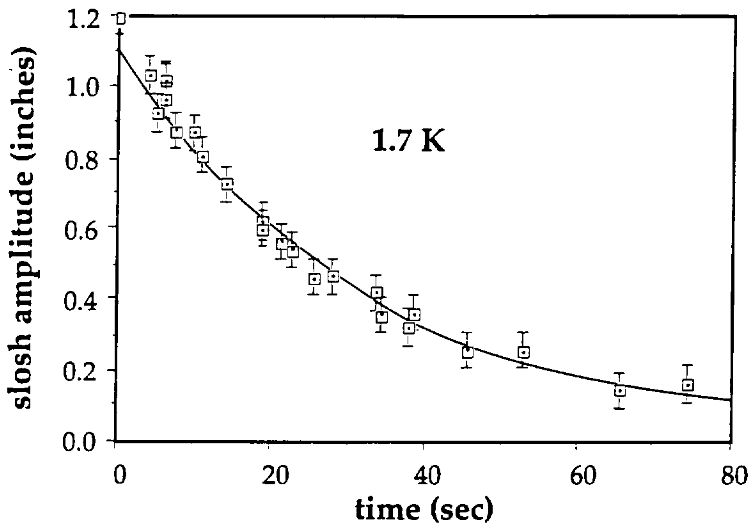

Figure 5-1: One-g Slosh Data. Data shows the experimental decay in the slosh amplitude.

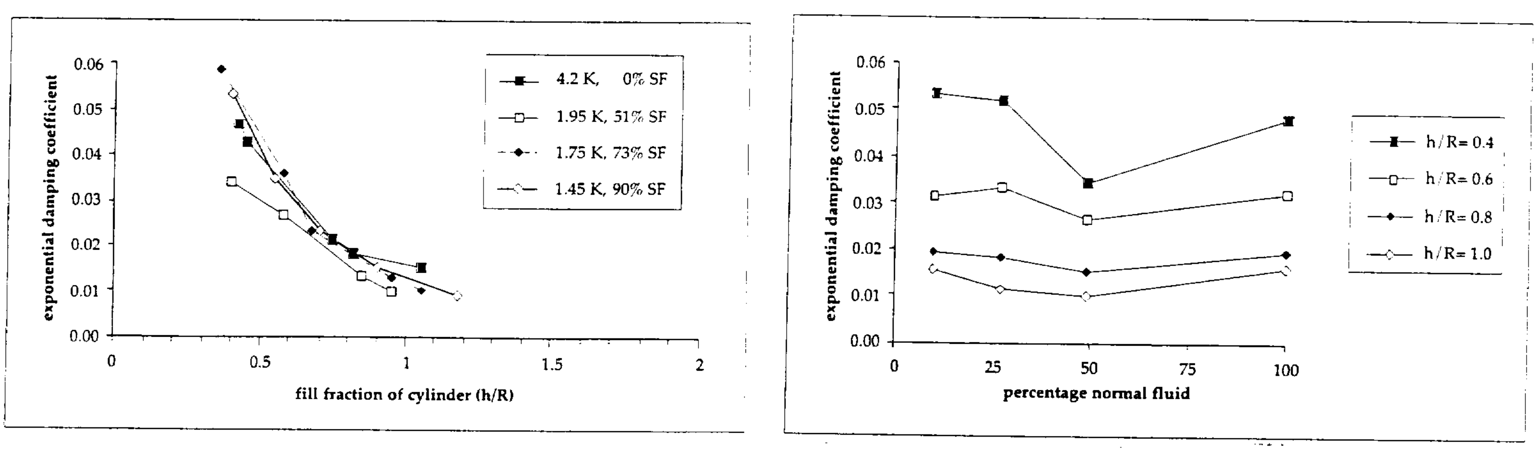

Figure 5-2: Exponential Damping Coefficient. Data shows weak correlation with temperature and strong correlation with fill level.

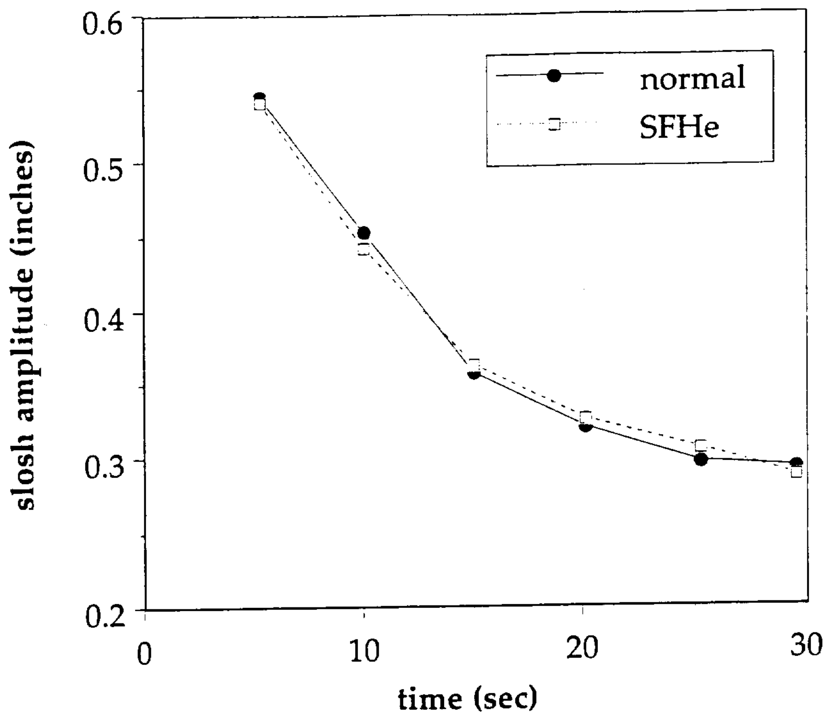

Figure 5-3: Predicted 1-g slosh amplitude. Both single and two-fluid model predict same behavior in 1-g.

5.2 HIGH TO LOW-G BEHAVIOR

A series of tests were performed to determine if fundamental frequencies could be correctly predicted based on the gravitational field. In these cases the gravitational field was sufficient to keep the fluid settled in the Test Cell.

Three methods of predicting fundamental frequency were used. The single and two-fluid models and a closed form relationship developed by McCarty and Stephens (ref. 8). Figure 5-4 shows a typical 0.02g simulation of the two-fluid model where the velocity of each the normal and superfluid component is displayed. Tracking the center of mass of the total fluid allows determination of the fundamental frequency. Figure 5-5 shows results of the models for a Test Cell approximately half full at 1.7K. It can be seen that there are no significant differences between models.

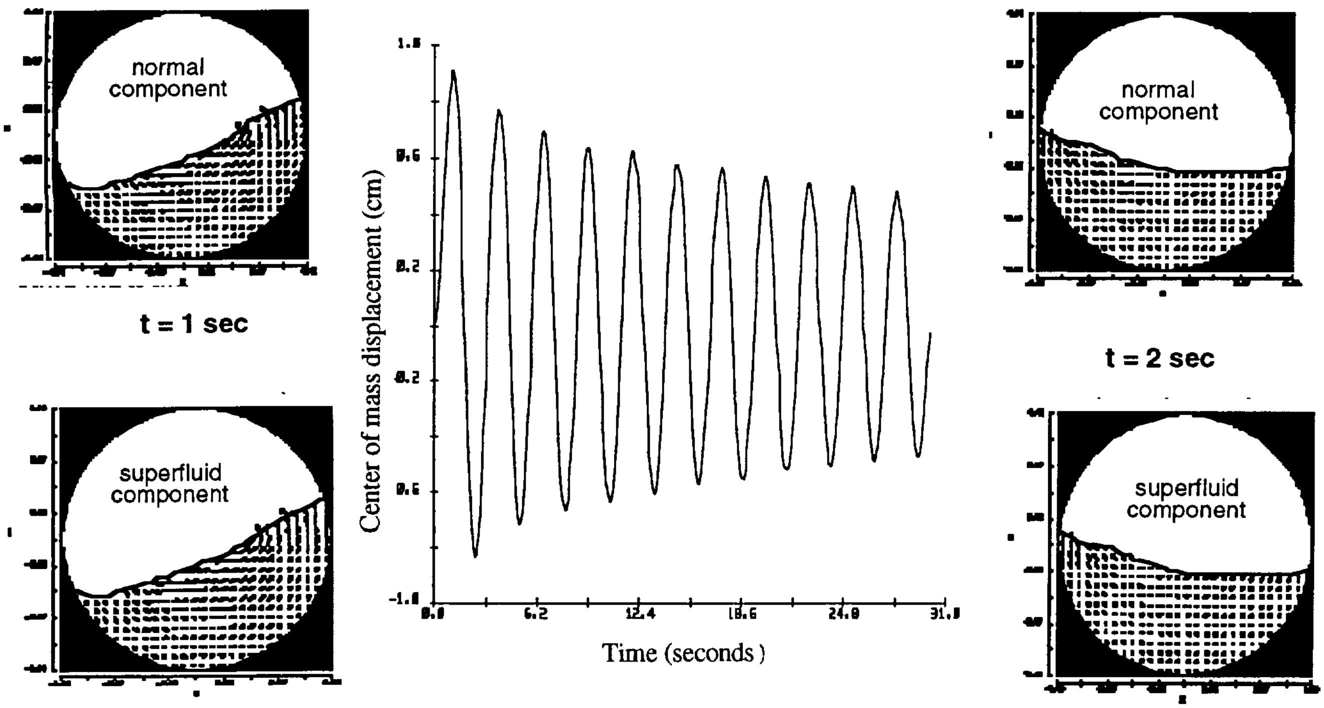

Figure 5-4: Two-fluid model simulation at 0.02g. Simulation shows fluid field of both the normal and superfluid components and time history of the center of mass.

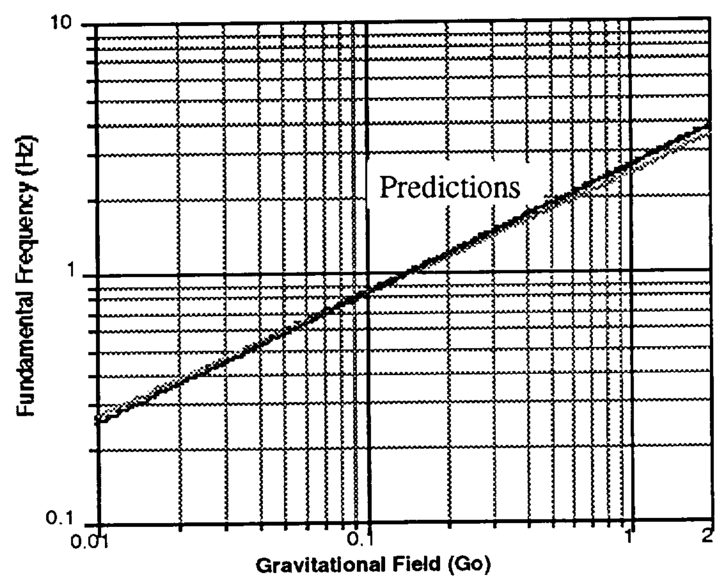

Figure 5-5: Three methods of predicting fundamental frequency. Predictions show no significant differences.

Figure 5-6 shows a picture of the fluid during the 0.04g acceleration. It can be seen that the liquid-vapor interface is still fairly dominated by the acceleration field. The Bond number based on the radius of the Cell is 334.6. Figure 5-7 shows the test data along with the predictions over the 12-50% fill level range tested. It can be seen that the fundamental frequency of the superfluid helium behaves and can be modeled as a single Newtonian fluid.

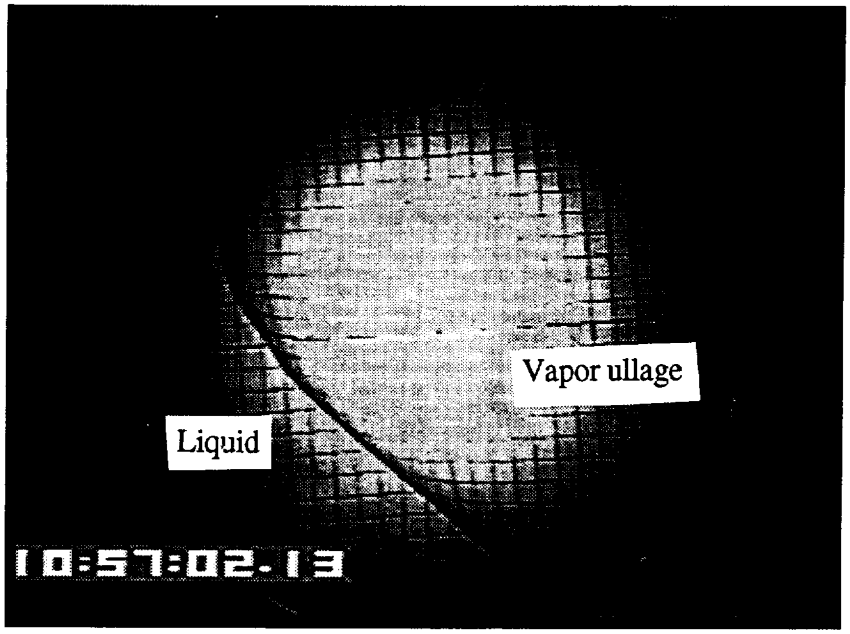

Figure 5-6: Superfluid helium in 0.04g field. The liquid-vapor interface is still dominated by the 0.04g acceleration field.

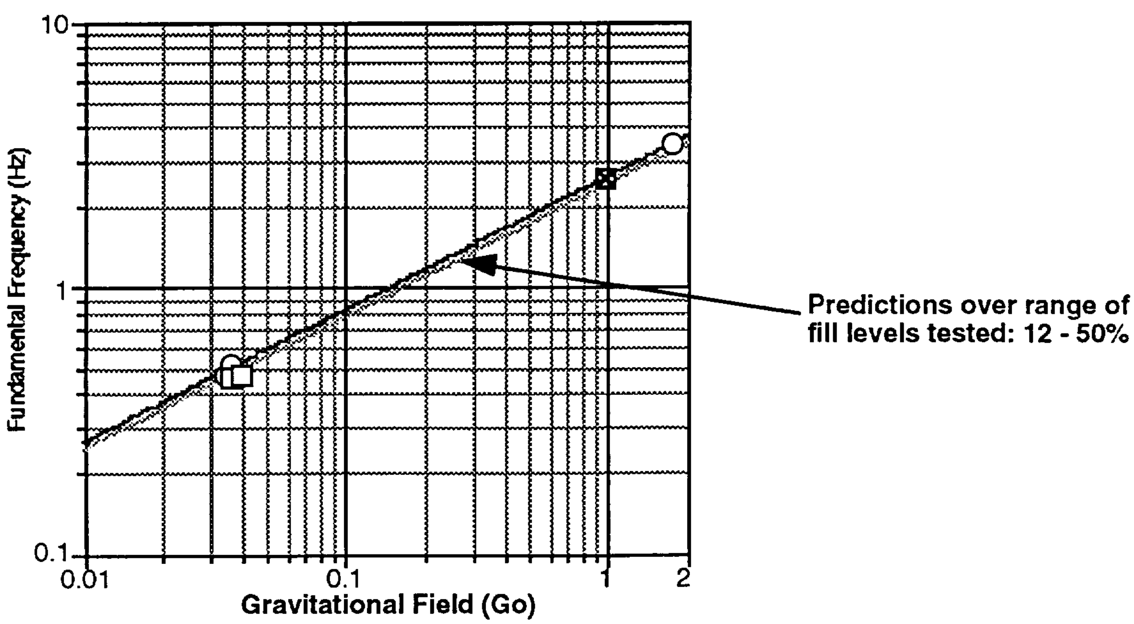

Figure 5-7: High to Low-g Test Results. Results indicate that fundamental frequency of superfluid helium behaves and can be modeled as a single Newtonian fluid.

5.3 ZERO-G BEHAVIOR

In zero gravity, the liquid-vapor interface profile is dominate by surface tension. The fluid takes on a profile to achieve it's lowest energy state which has a single vapor ullage. In a large tank this ullage will be spherical. In the case of this 2D Test Cell the ullage is nearly in the form of a disc. Figure 5-8 shows a prediction of the movement of the fluid in 0-g after being subjected to a lateral disturbance of 1 mili-g for 1 second. Figure 5-9 shows the plots of the center of mass of the fluid predicted by the single and two-fluid models. It can be seen that in zero-g, the two models predict different damping of the fluid with the two-fluid prediction showing a higher damping rate.

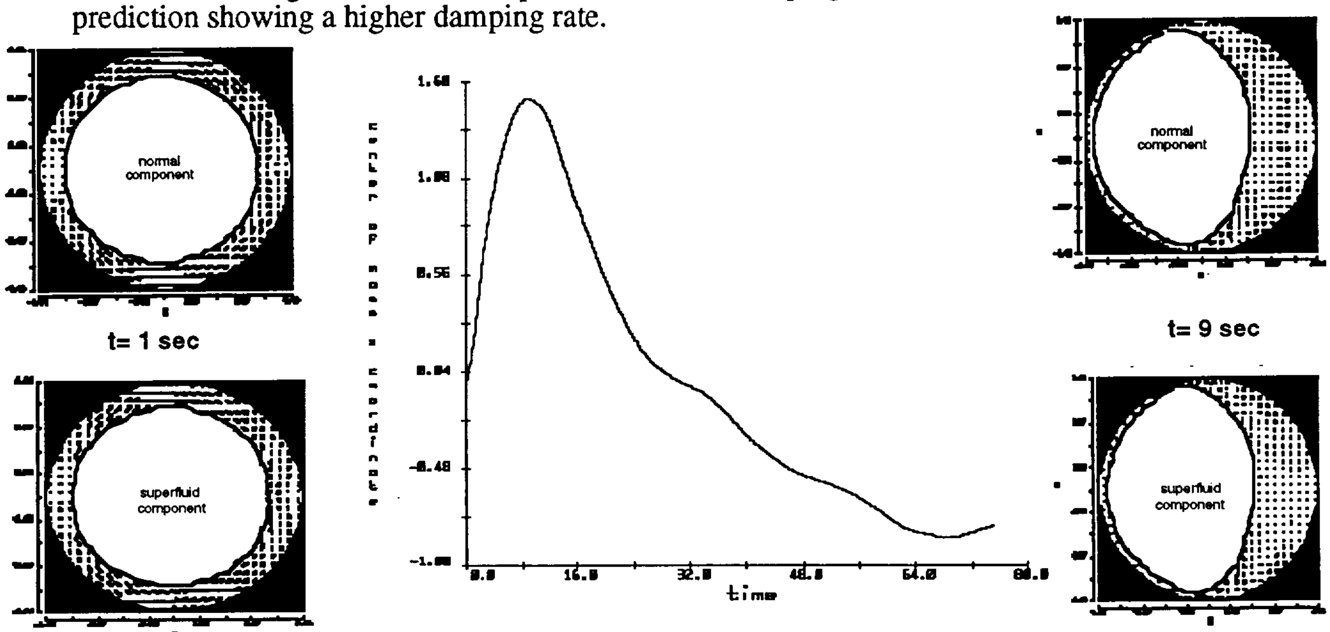

Figure 5-8: Predicted two-fluid zero-gravity fluid movement. Figure shows movement of the fluid after being subjected to a lateral disturbance of 1 mili-g for 1 second.

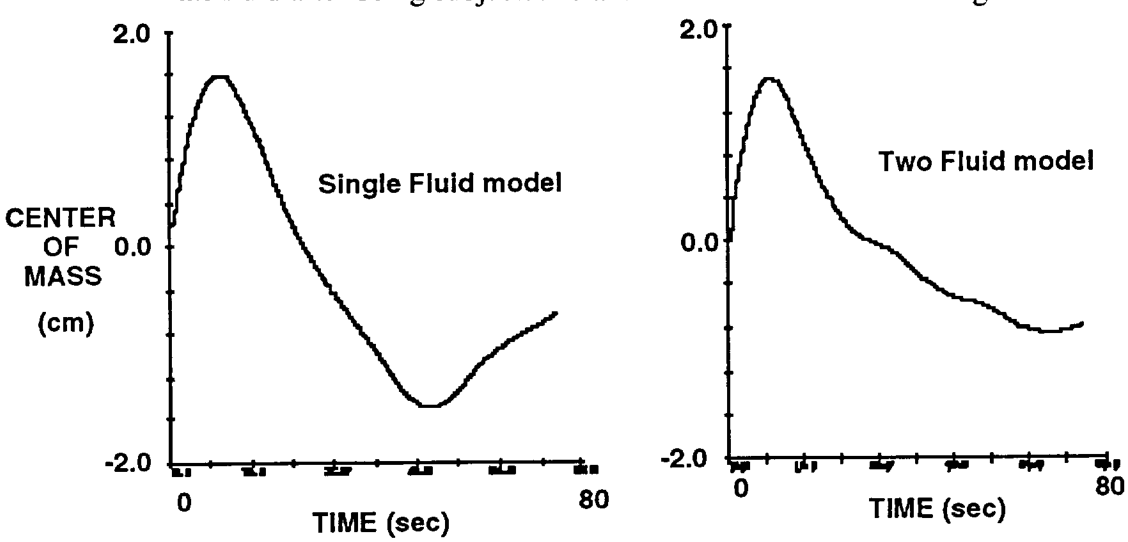

Figure 5-9: Center of mass of the fluid predicted by the single and two-fluid models in zero-g. The two models predict different damping of the fluid with the two-fluid prediction showing a higher damping rate.

A series of test were performed at zero-gravity with the experimental Float Package free-floating in the aircraft. After entering the zero gravity trajectory, the fluid would transition from a high-g profile to the zero-gravity disc profile as shown in figure 5-10.

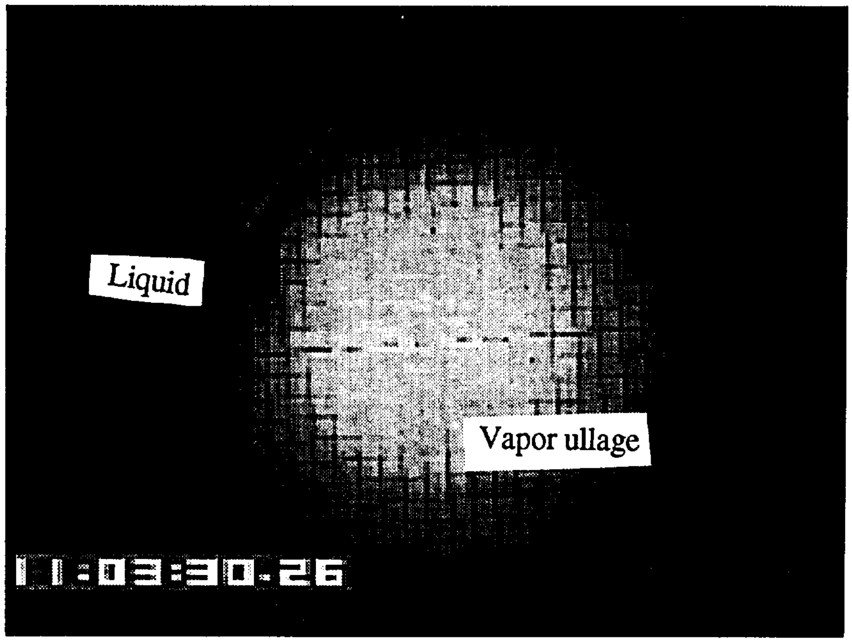

Figure 5-10: Zero-gravity profile of the fluid. Fluid liquid/vapor interface forms a circular shape as predicted.

Unfortunately prior to entering the low-gravity profile, the fluid would not have sufficient time to come to rest. The fluid would initially be settled in the Test Cell and "rocking" from side to side at a frequency based on the gravity field. Once the fluid would achieve it's low-gravity profile, residual velocities of the fluid would cause a surface wave that would rotate around the circular liquid/vapor interface as depicted in figure 5-11. At the same time, tests were performed to determine the bulk fluid's fundamental (lateral). The video of the fluid in the low-gravity was analyzed to record the fluid movement frequencies.

Results showed that the surface wave would have a frequency of approximately 0.37 Hz meaning that a surface wave in the fluid would take approximately 2.7 seconds to travel one full revolution. Due to the short time that the float package would experience near zero-g, the frequency of the lateral mention of the fluid was hard to determine. As stated previously, the time available near zero-g was 6-7 seconds for a very good float of the package. Review of the data shows that the lateral frequency appeared to be on the order of 0.1 Hz. This results is within an order of magnitude of those predicted for zero-g and close to those predicted for levels of 10 mili-G. It must be noted that the float package would never get to zero-g since the attached data umbilical cable would leave forces which were estimated to be up to in the mili-g range which are in the range of the accuracy of the accelerometers on the float package.

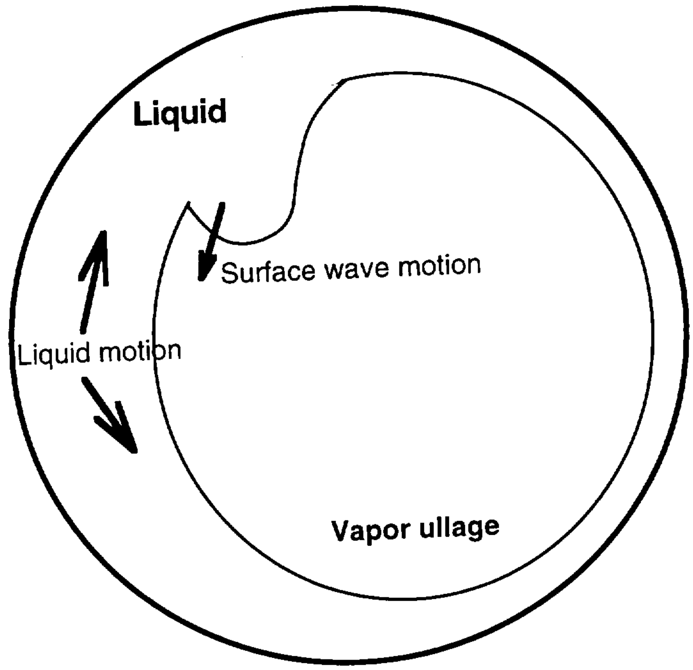

Figure 5-11: Depiction of recorded fluid motion. The fluid motion is a composite of a surface wave and lateral motion of the bulk fluid.

6. SUMMARY

Results of tests show that modeling of SFHe in 1-g can be accomplished with single-fluid models which will accurately predict fundamental frequencies and damping of the fluid motion. Over a range of accelerations were surface tension forces are not dominant, both single and two-fluid models predict fundamental frequencies.

The main interest to designers of spacecraft attitude control systems are frequencies in zero-g. Based on the results of these tests it can be said that computational fluid dynamic codes (both single and two-fluid models) can correctly predict frequencies for superfluid helium over a wide range of accelerations. There does not appear to be an unique behavior of superfluid helium that would lead one to believe that frequencies of such a fluid can not be predicted. The low predicted frequency of the fluid motion in zero appears to be correct. This is of importance to designers of spacecraft attitude control designers. Typically these low frequencies would not of concern since typical control systems have large enough capability to control them.

Verification of these code predictions will aid in the design of control systems for satellites carrying SFHe such as the Space Infrared Telescope Facility (SIRTF), the Relativity Mission (GP-B), the Low Temperature Microgravity Physics Facility (Space Station), and other planned orbital helium systems such as the Satellite Test of the Equivalence Principle (STEP). Results of this project shows that control designers can be comfortable with established tools for predicting frequencies of superfluid helium.

The test durations available in low-gravity aircrafts are not sufficiently long enough to get data to verify damping coefficients of the fluid motion. In order to get data on damping coefficients in zero-gravity, tests would have to be performed in long durations. A flight definition of a long duration experiment was the subject of a proposal entitled "Dynamic Motion of Superfluid Helium" which was submitted in response to NRA 94-OLMSA-05 but not selected.

7. ACKNOWLEDGMENTS

This work was performed under the MSAD NRA research project NASW-4803. The author wishes to thank the JPL team for the support with the Low Temperature Facility, and the NASA Lewis DC-9 Aircraft.

8. REFERENCES

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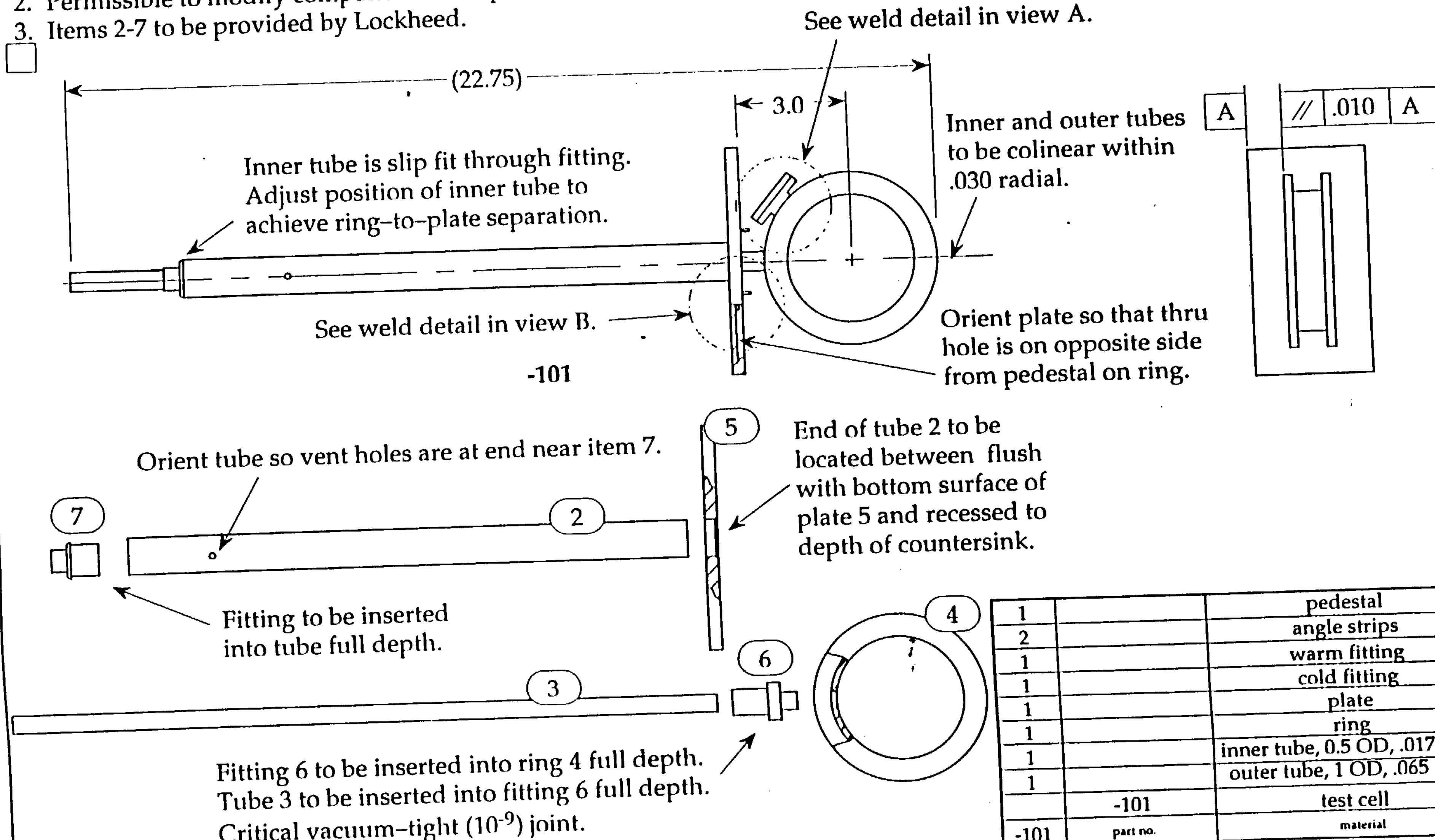
APPENDIX A: TEST CELL MECHANICAL DRAWINGS

notes:

1. Appucation is at liquid helium temperature (2 K) and requir. .acuum–tight (10^{-9}) joints.
2. Permissible to modify components to improve weld.
3. Items 2-7 to be provided by Lockheed.



1		pedestal	9
2		angle strips	8
1		warm fitting	7
1		cold fitting	6
1		plate	5
1		ring	4
1		inner tube, 0.5 OD, .017 x 18	3
1		outer tube, 1 OD, .065 x 15	2
1	-101	test cell	1
-101	part no.	material	[illegible]

tolerances unless otherwise specified	
.xxx	± .003
.xx	± .010
.x	± .050

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Stainless Steel SFHe Test Cell Assembly

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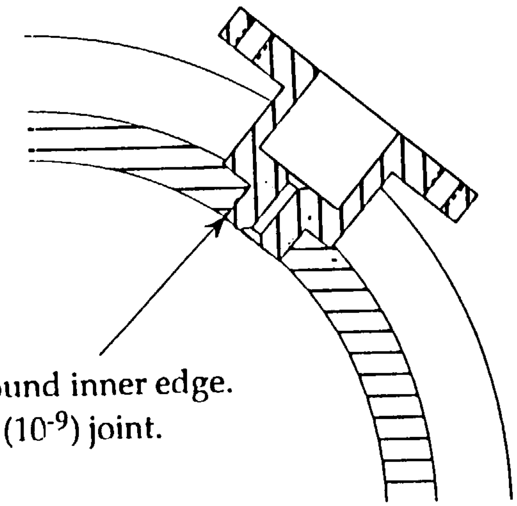
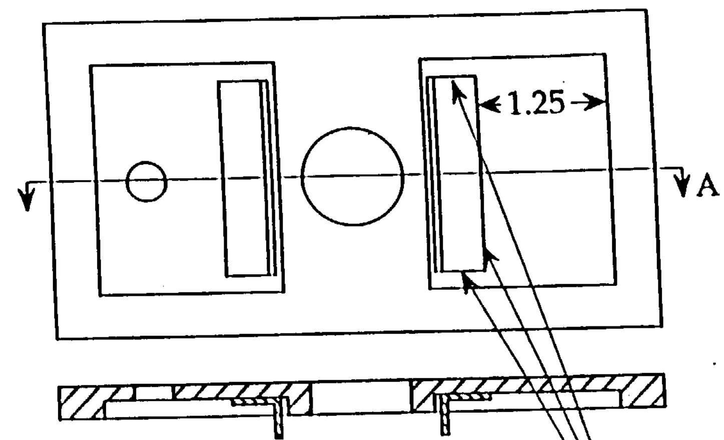


Weld FN 9 to FN 4 around inner edge.
Critical vacuum–tight (10^{-9}) joint.

View A



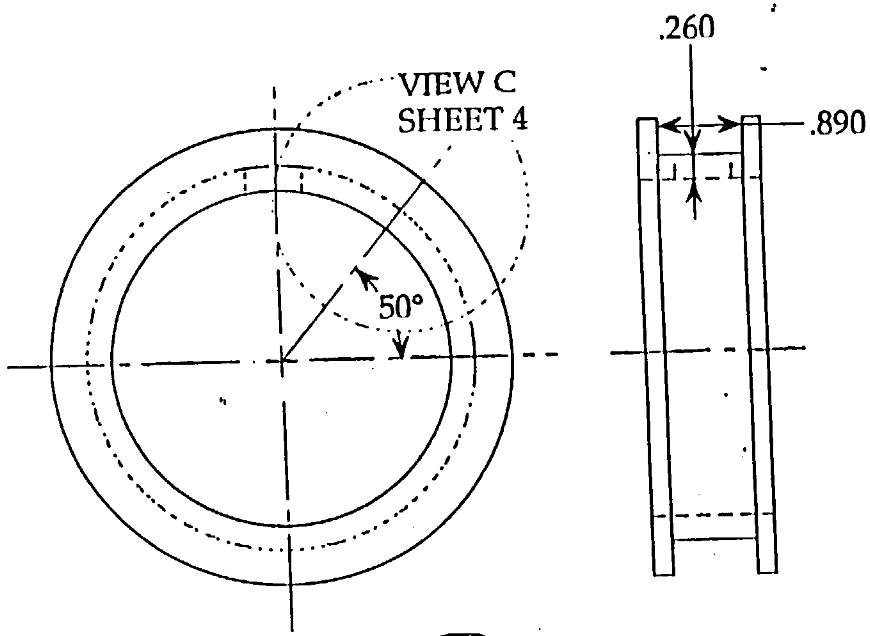
Weld FN 8 to FN 5 along 3 exposed sides, two places. Side of FN 8 with existing holes to be standing up from FN 5. Center long axis of FN 8 in recess of FN 5.

View B

REVISIC

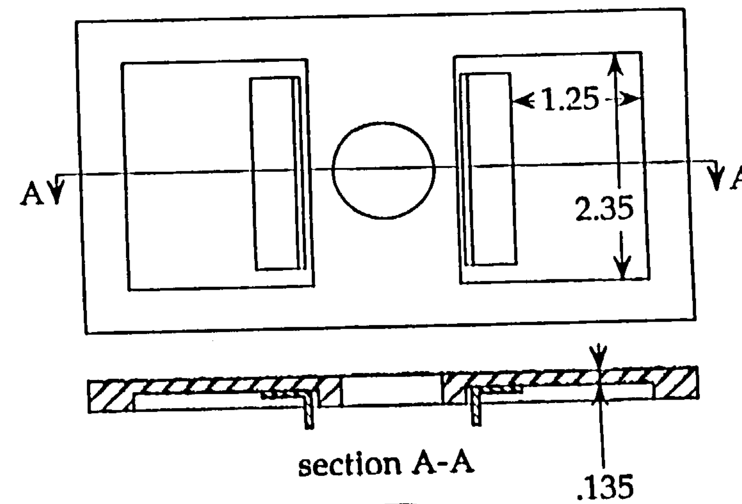
notes:

1. Application is at liquid helium temperature (2 K) and requires vacuum–tight (10^{-9}) joints.
2. Machine a flat on the external radius of FN 2 betweenthe flanges similar to the existing flat. Depth of cut to be determined by thickness from inner radius to surface of flat along radial line. Flat to be centered between the flanges.
3. Modify FN 1 as shown in view C.
4. Verify that -102 fits into the new hole in FN 1. Minimum clearance is desired for laser welding.
5. Permissible to substitute .030 radius in place of countersink. For either method, remove all burrs or sharp edges which might damage insulated wires passing through this hole.
6. Break all sharp edges.



1

(as delivered from JPL)



section A-A

2

(as assembled from JPL–supplied components)

	part no.	component name	material
	-102	C-seal pedestal	321 stainless steel
	-101	C-seal plate	321 stainless steel
		plate	321 stainless steel
3		ring	321 stainless steel

tolerances unless otherwise specified	
.xxx	± .003
.xx	± .010
.x	± .050

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Feedthru Connector Installation

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CONTRACT NASW-4803 | 20 Feb 95 | sheet 1 of

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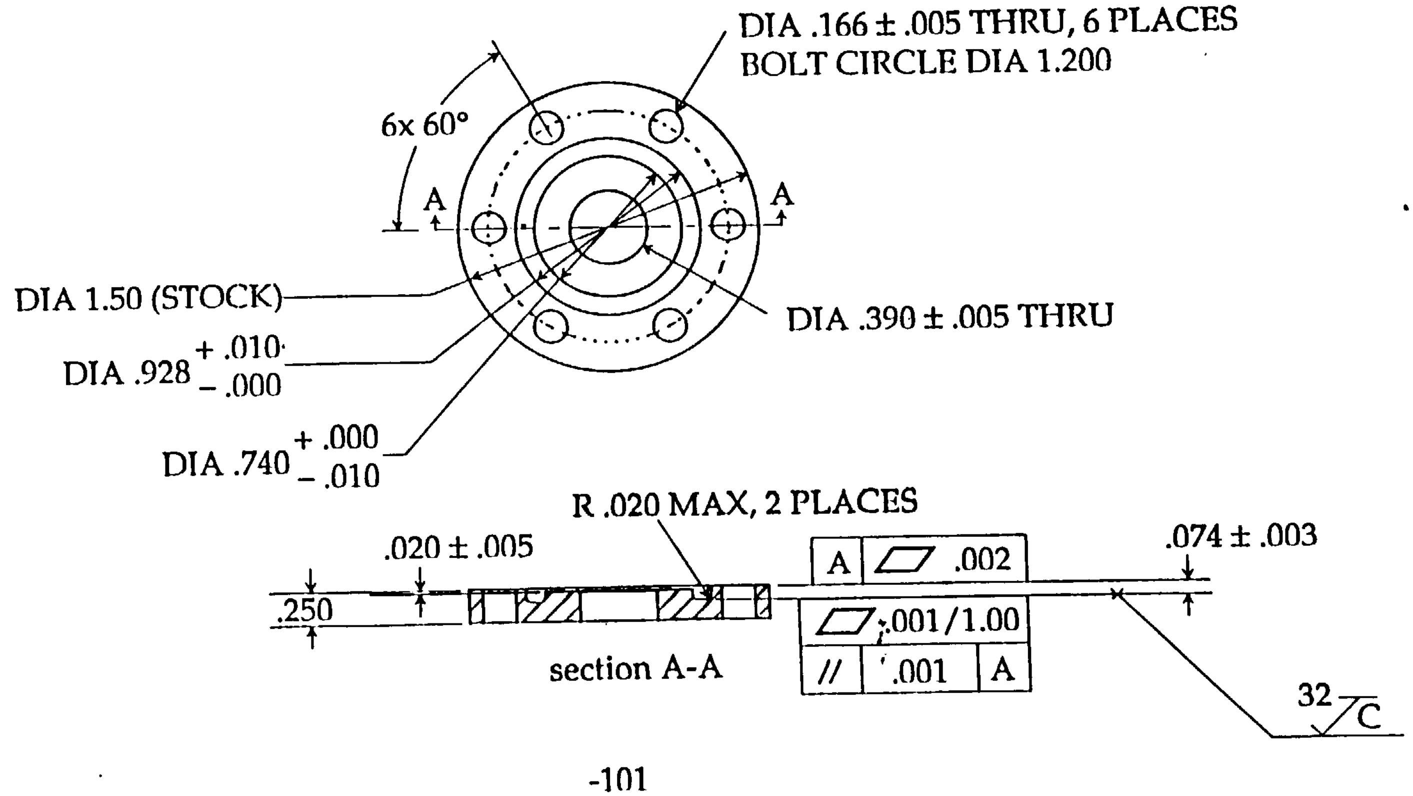
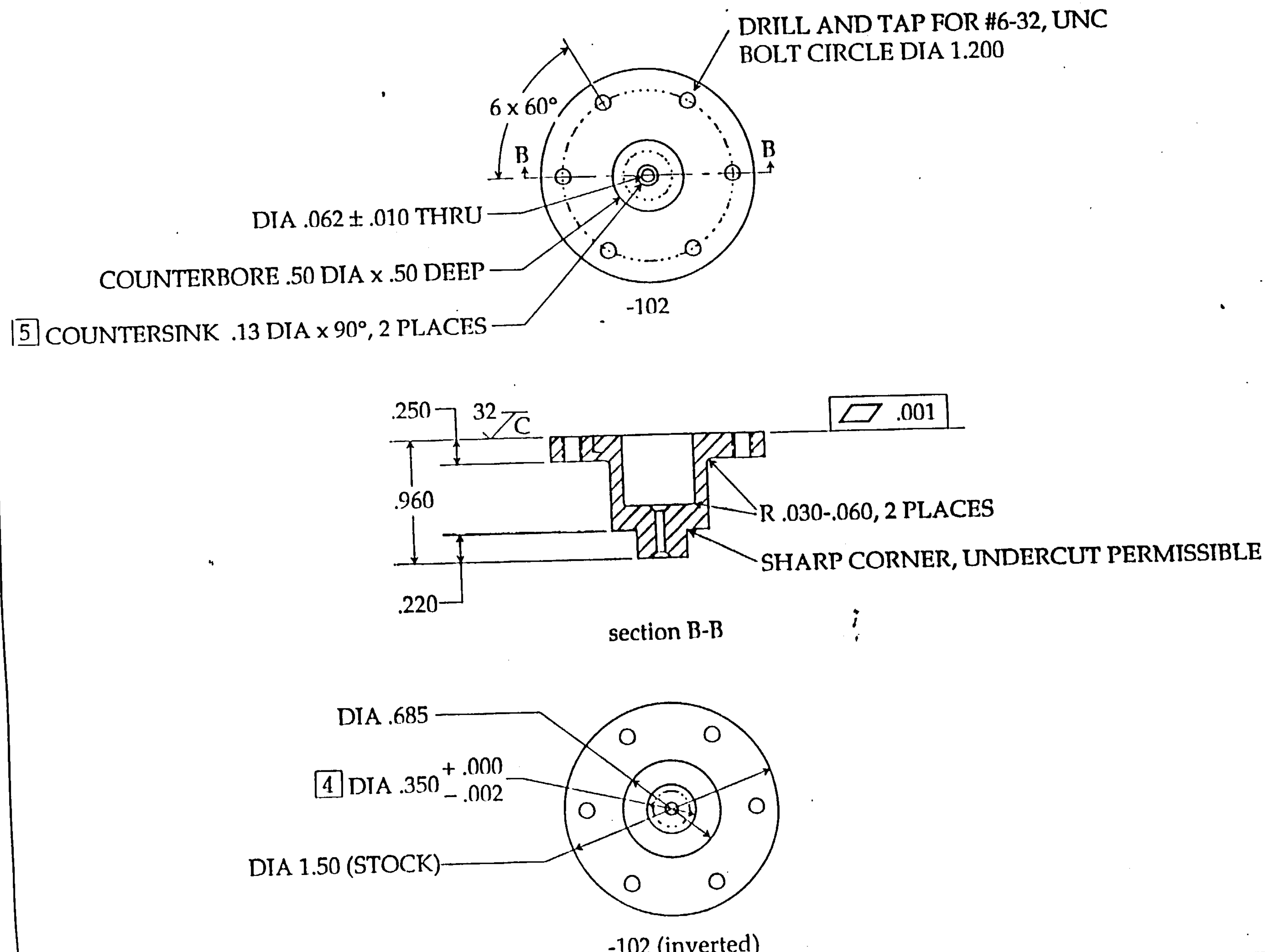


SLOSH - 007	REV nc	sheet 2 of



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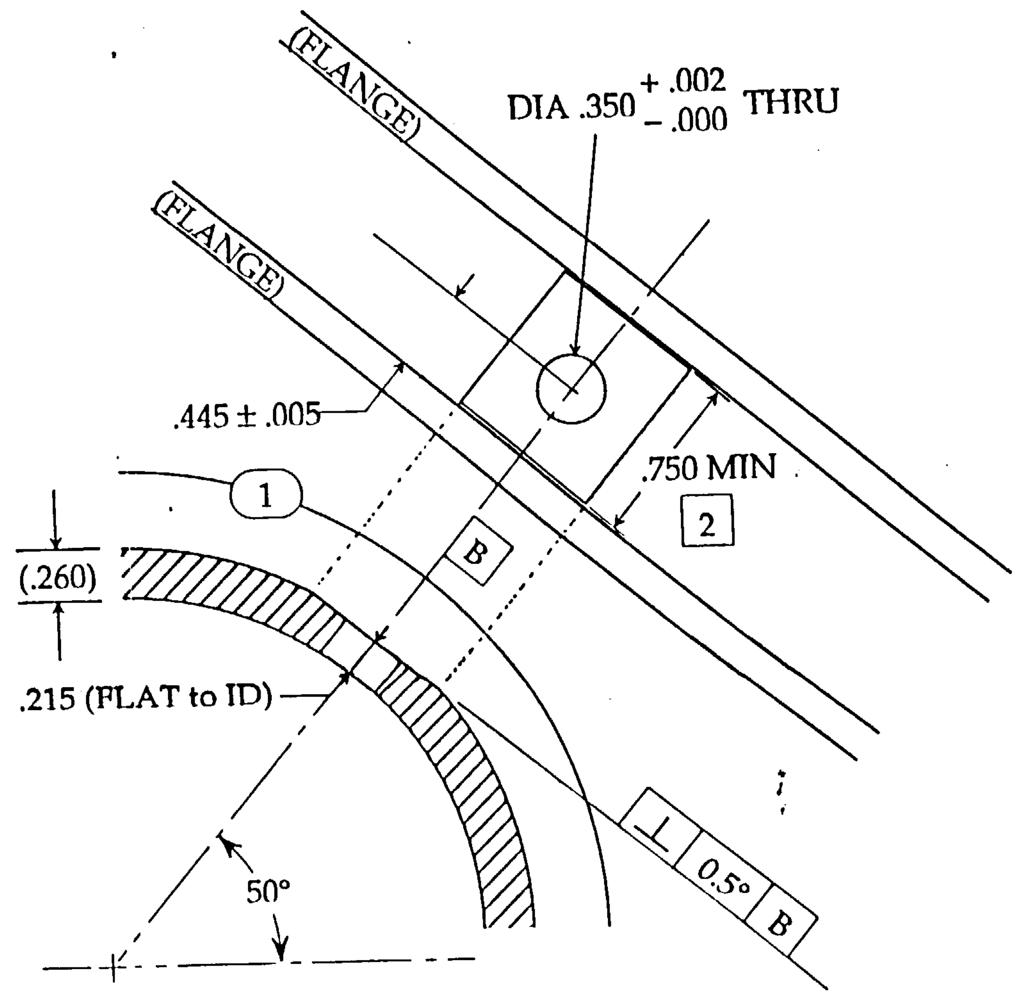
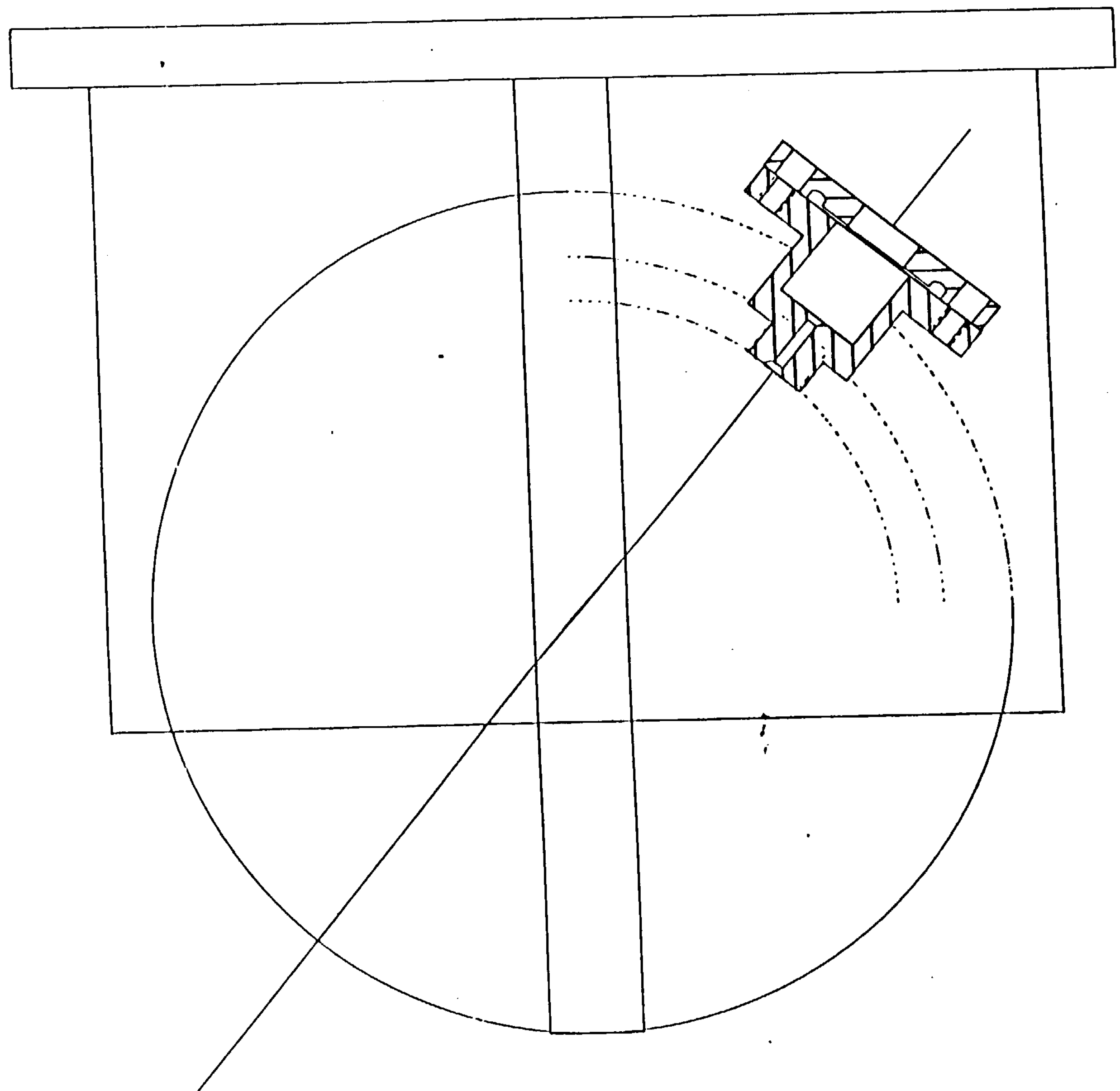


VIEW C
Modifications to FN 1
(shown in section for clarity)



LAYOUT
(for reference only)

SLOSH - 007	REV nc	sheet 5 of